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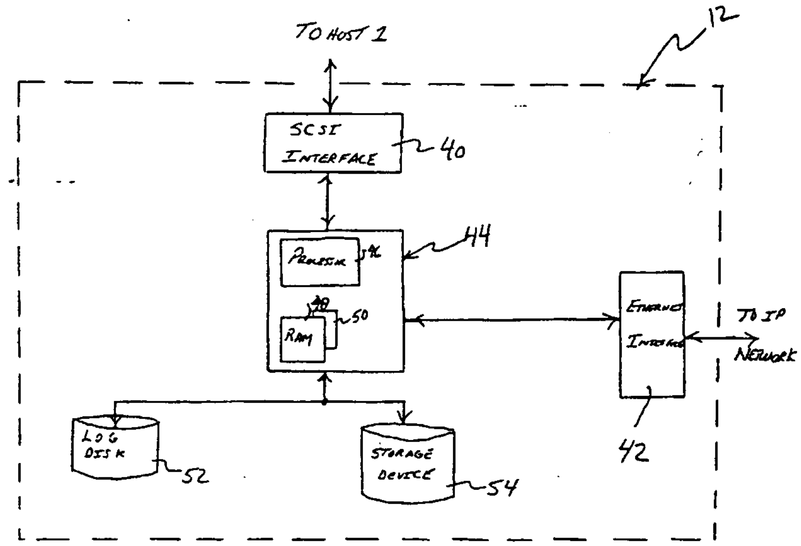
(54) Title: SCSI-TO-IP CACHE STORAGE DEVICE AND METHOD



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(57) Abstract: A SCSI-to-IP cache storage system interconnects a host computing device or a storage unit to a switched packet network. The cache storage system includes a SCSI interface (40) that facilitates system communications with the host computing device or the storage unit, and an Ethernet interface (42) that allows the system to receive data from and send data to the Internet. The cache storage system further comprises a processing unit (44) that includes a processor (46), a memory (48) and a log disk (52) configured as a sequential access device. The log disk (52) caches data along with the memory (48) resident in the processing unit (44), wherein the log disk (52) and the memory (48) are configured as a two-level hierarchical cache.

SCSI-to-IP CACHE STORAGE DEVICE AND METHOD

PRIORITY INFORMATION

This application claims priority from provisional application Serial No. 60/312,471 filed August 15, 2002. This provisional application is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The invention relates to the field of data back-up systems, and in particular to a SCSI-to-IP cache storage device and method for implementing SAN over the Internet.

As we enter a new era of computing, data storage has changed its role from a secondary with respect to CPU and RAM, to a primary role in today's information world. Online data storage doubles approximately every nine months due to the increasing demand for network information services. While the importance of data storage is well-known, published literature is limited in the computer architecture research community reporting networked storage architecture. This situation will change quickly as information has surpassed raw computational power as the important commodity. This is especially true for Internet dependent businesses.

In general networked storage architectures have evolved from network-attached storage (NAS), storage area network (SAN), to more recent storage of IP (iSCSI). NAS architecture allows a storage system/device to be directly connected to a standard network, typically via the Ethernet. Clients on the network can access the NAS directly. A NAS based storage subsystem has a built-in file system to provide clients with file system functionality. SAN technology, on the other hand, provides a simple block level interface for manipulating nonvolatile magnetic media. Typically, a SAN includes networked storage devices interconnected through a dedicated Fibre Channel network. The basic premise of a SAN is to replace the current "point-to-point"

infrastructure with one that allows "any-to-any" communications. A SAN provides high connectivity, scalability, and availability using a specialized network interface - the Fibre Channel network. Deploying such a specialized network usually introduces cost for implementation, maintenance, and management. iCSI is the most recent emerging technology with the goal of implementing the SAN technology over the better-understood and mature network infrastructure, the Internet (TCP/IP).

Implementing SAN over IP brings economy and convenience whereas it also raises issues such as performance and reliability. Currently, there are basically two approaches: one encapsulates SCSI protocol in TCP/IP at host bus adapter (HBA) level, and the other carries out SCSI and IP protocol conversion at a specialized switch. However, both approaches have severe performance limitations. To encapsulate SCSI protocol over IP requires a significant amount of overhead traffic for SCSI command transfers and handshaking over the Internet. Converting protocols at a switch places a special burden on an already overloaded switch and creates another specialized piece of network equipment in the SAN. Furthermore, the Internet was not designed for transferring data storage blocks. Many features such as Maximum Transfer Unit (MTU), data gram fragmentation, routing, and congestion control may become obstacles to providing enough instant bandwidth for large block transfers of storage data.

Therefore, there is a need for a system that can implements SAN over switched packet network, such as for example the Internet (TCP/IP).

SUMMARY OF THE INVENTION

Briefly, according to an aspect of the invention, a SCSI-to-IP cache storage system includes a SCSI interface that facilitates system communication with host computers and extended storage devices. The system also includes an Ethernet interface that allows the system to receive data from and send data to the Internet, and a processing unit that includes a processor and memory. The system also includes a log disk that is a sequential access device. The log disk is used to cache data along with the memory resident in the processing unit. The log disk and the memory are configured as a two-level hierarchical cache for a disk storage device within the SCSI-to-IP cache storage system.

The system of the present invention facilitates implementing SAN over the Internet. The disk storage device within the SCSI-to-IP cache storage system is preferably configured as RAID.

Besides the regular data storage in the SCSI-to-IP cache storage system, one storage device within the system is used as a non-volatile cache that caches data coming from possibly two directions. That is, block data may come from the SCSI interface, and network data may come from the Ethernet interface. In addition, to standard SCSI and IP protocols running on the intelligent processing unit, a local file system may also reside in the processing unit. The file system is preferably a simplified Log-structured file system that writes data quickly and provides advantages to cache data both ways. Besides caching storage data in both directions, the SCSI-to-IP cache storage systems may also localize SCSI commands and handshaking operations to reduce unnecessary traffic over the Internet. In this way, the SCSI-to-IP cache storage system acts as a storage filter to discard a fraction of the data that would otherwise move across the

Internet, reducing the bottleneck imposed on limited Internet bandwidth and increasing storage data rate.

The system of the present invention provides an iSCSI network cache to smooth out the traffic and improve system performance. Such a cache or bridge is not only helpful but also necessary to a certain degree because of the different nature of SCSI and IP such as speed, data unit size, protocols and requirements. Wherever there is a speed disparity, cache of course helps. Analogous to cache memory used to cache memory data for a CPU, the SCSI-to-IP cache storage system is a cache storage used to cache networked storage data for a server host.

The system of the present invention may utilize the Log-structured file system to write data to magnetic media for caching data coming from both directions (e.g., from the Internet and from the host). In addition, since the SCSI-to-IP cache storage system preferably uses log disk to cache data, it is a nonvolatile cache, which is of course desirable for caching storage data reliably since once data is written to storage, it is considered safe.

The SCSI-to-IP cache storage system allows direct connection to a SCSI interface of a computer that in turn can access a SAN implemented over the Internet. In addition, by localizing part of the SCSI protocol and filtering of some unnecessary traffic, the SCSI-to-IP cache storage system can reduce the bandwidth requirement of the Internet to implement the SAN.

These and other objects, features and advantages of the present invention will become apparent in light of the following detailed description of preferred embodiments thereof, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustration of a distributed computing and information backup

system that includes a SCSI-to-IP cache storage system;

FIG. 2 is a block diagram illustration of one the SCSI-to-IP cache storage systems illustrated in FIG. 1;

FIG. 3 is a block diagram illustration of a RAM buffer layout; and

FIG. 4 is a block diagram illustration of a SCSI initiator and target sub-systems.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a block diagram illustration of a distributed computing and information backup system 10 that includes a plurality of SCSI-to-IP cache storage systems 12-15. Each of the plurality of SCSI-to-IP cache storage systems 12-15 interfaces one of an associated networked device such as a host 18, 20 or a storage device 22, 24 to the Internet. The distributed computing and information backup system 10 also includes network attached storage (NAS) 26 that communicates via the Internet. The system 10 provides a SAN implementation over IP using the SCSI-to-IP cache storage systems 12-15. Although the system 10 illustrated in FIG. 1 includes four SCSI-to-IP cache storage systems 12-15, one of ordinary skill will recognize that virtually any number of computing devices or storage devices can be connected through an associated SCSI-to-IP cache storage system to form the SAN. Significantly, rather than using a specialized network or storage switch, the SCSI-to-IP cache storage systems 12-15 connect a host computer or a storage device to the IP network. The SCSI-to-IP cache storage systems 12-15 each provide SCSI protocol service, caching service, naming service and protocol service.

FIG. 2 is a block diagram illustration of one of the SCSI-to-IP cache storage systems 12. This cache storage system 12 includes a SCSI interface 40 that supports SCSI communication with the host 18 (FIG. 1) and runs in a target mode receiving requests from the host 18 (FIG. 1),

carrying out the I/O processing through the network, and sending back results to the host 18 (FIG. 1). When the SCSI-to-IP cache storage system is used to connect a storage device such as a disk or RAID 22 (FIG. 1) to extended storage, the SCSI-to-IP cache storage system operates in an initiator mode, wherein it sends/forwards SCSI requests to the extended storage mode. Referring to FIG. 1, the SCSI-to-IP cache storage system 12 operates in target mode, while the SCSI-to-IP cache storage system 15 operates in initiator mode. The SCSI-to-IP cache storage system 12 acts as a directly attached local storage device to the host 18 (FIG. 1).

Referring still to FIG. 2, the SCSI-to-IP cache storage system 12 also includes an Ethernet interface 42, which connects the SCSI-to-IP cache storage system to the Internet. A processing unit 44 that includes a processor 46 and RAM 48 is also included in the cache storage system 12. The processing unit 44 executes a log-structured file system, SCSI protocol and IP protocols. The RAM 48 is primarily used as a buffer cache. NVRAM 50 (e.g., 1- 4 MB) is also included to maintain meta data such as a hash table, LRU list, and mapping information (STICS_MAP). The meta data is stored in the NVRAM 50 before being written to disk. This of course reduces the frequency of having to write or read meta data to/from disk. Alternatively, it is contemplated that Soft Updates as disclosed in the printed publication by G. Granger, M. McKusick, C. Soules and Y. Pratt, *"Soft Updates: A Solution to the Metadata Update Problem in File Systems"*, ACM Transactions on Computer Systems, Vol. 18, No. 2, 2000, pp. 127-135 may be used to keep meta data consistency without using NVRAM. This paper is hereby incorporated by reference.

The SCSI-to-IP cache storage system 12 further comprises a log disk 52, which is a sequential accessed device. The log disk is used to cache data along with the RAM within the processing unit 44. The log disk 52 and the RAM form a two-level hierarchical cache.

The system 12 also includes a storage device 54. The storage device 54 may be configured as a disk, a RAID, or just-bunch-of-disks (JBOD). The storage device 54 can be considered a local disk from the point of view of the host 18 (FIG. 1). From the point of view of the IP network via the network interface 42, the storage device 54 is considered as a component of a networked storage system such as a SAN with an IP address as its ID.

To allow a true "any-to-any" communication between servers and storage devices, a global naming is required. In one embodiment, each of the SCSI-to-IP cache storage systems 12-15 (FIG. 1) is named by a global location number (GLN) which is unique for each of the SCSI-to-IP cache storage systems. An IP address is assigned to each SCSI-to-IP cache storage system and use this IP as the GLN.

The cache organization in the SCSI-to-IP cache storage system includes a two level hierarchy: a RAM cache and a log disk. Frequently accessed data reside in the RAM, which is organized as a LRU cache 58 as shown in FIG. 3. Whenever the newly written data in the RAM are sufficiently large or whenever the log disk 52 (FIG. 2) is free, data are written into the log disk. There are also less frequently accessed data kept in the log disk. Data in the log disk are organized in the format of *segments* similar to that in a Log-structured File System. A segment contains a plurality of *slots* each of which can hold one data block. Data blocks in segments are addressed by their *Segment* IDs and *Slot IDs.*

One of the challenging tasks in this research is to design an efficient data structure and a search algorithm for RAM cache. As shown in FIG. 3, the RAM cache includes a hash table that is used to locate data in the cache, a data buffer which contains several data slots, and a few In-memory headers. Data blocks stored in the RAM cache are addressed by their *Logical Block Addresses (LBAs).* The hash table contains location information for each of the valid data blocks

in the cache and uses LBAs of incoming requests as search keys. The slot size is set to be the size of a block. A slot entry includes the following fields:

- An LBA entry that is the LBA of the cache line and serves as the search key of hash table;
- Global Location Number (GLN) if the slot contains data from or to other STICS.
- A log disk LBA is divided into at least two parts:

1. A state tag (2 bits), used to specify where the slot data is: IN_RAM_BUFFER, IN_LOG_DISK, IN_DATA_DISK or IN_OTHER_STICS;

2. A log disk block index (e.g., 30 bits), used to specify the log disk block number if the state tag indicates IN_LOG_DISK. The size of each log disk can be up to for example 2^{30} blocks.

- Two pointers (hash_prev and hash_next) are used to link the hash table;
- Two pointers (prev and next) are used to link the LRU list and FREE list;
- A Slot-No is used to describe the in-memory location of the cached data.

As set forth above, the SCSI-to-IP cache storage system may run under two modes: (i) initiator mode or (ii) target mode. FIG. 4 is a block diagram illustration of the SCSI-to-IP cache storage system initiator 100 and target modes 110. When running in target mode, the SCSI-to-IP cache storage system is connected to a host and the host is running in initiator mode. Otherwise the SCSI-to-IP cache storage system runs in initiator mode. Initiator mode is the default mode of the SCSI-to-IP cache storage system. All server host platforms including Linux support SCSI initiator mode. The standard SCSI initiator mode operates in the SCSI-to-IP cache storage system. The SCSI target runs in parallel to the initiator and is concerned only with the processing of SCSI commands. A set of target APIs is defined for the SCSI-to-IP cache storage

system. These APIs include SCSI functions such as SCSI_DETECT, SCSI_RELEASE, SCSI_READ, SCSI_WRITE and etc. When running under target mode, a SCSI-to-IP cache storage system looks like a standard SCSI device to a connected host.

For each the SCSI-to-IP cache storage system, a variable STICS_LOAD is defined to represent its current load. The higher the STICS_LOAD, the busier the SCSI-to-IP cache storage system is. When a SCSI-to-IP cache storage system starts, its STICS_LOAD is set to zero. When the SCSI-to-IP cache storage system accepts a request, STICS_LOAD is decremented. Besides STICS_LOAD, STICS_MAP is defined to map all the SCSI-to-IP cache storage system loads within the network. STICS_MAP is a set of <GLN, STICS_LOAD> pairs. The STICS_MAP is also updated dynamically.

Write requests may come from one of two sources: the host via the SCSI interface and from another SCSI-to-IP cache storage system via the Ethernet interface. The operations of these two types of writes are as follows.

After receiving a write request from the host via the SCSI interface, the SCSI-to-IP cache storage system searches the hash table by the LBA address. If an entry is found, the entry is overwritten by the incoming write. Otherwise, a free slot entry is allocated from the Free List, the data are copied into the corresponding slot, and its address is recorded in the hash table. The LRU list and Free List are then updated. When enough data slots (e.g., sixteen) are accumulated or when the log disk is idle, the data slots are written into log disk sequentially in one large write. After the log write completes successfully, the SCSI-to-IP cache storage system signals the host that the request is complete.

A packet coming from another the SCSI-to-IP cache storage system via the Ethernet interface may turn out to be a write operation from a remote SCSI-to-IP cache storage system on

the network. After receiving such a write request and unpacking the network packet, SCSI-to-IP cache storage systems gets a data block with GLN and LBA. It then searches the Hash Table by the LBA and GLN. If an entry is found, the entry is overwritten by the incoming write. Otherwise, a free slot entry is allocated from the Free List, and the data are then copied into the corresponding slot. Its address is recorded in the Hash Table. The LRU list and Free List are updated accordingly.

Similar to write operations, read operations may also come either from the host via the SCSI interface or from another SCSI-to-IP cache storage system via the Ethernet interface.

After receiving a read request from the host via the SCSI interface, the SCSI-to-IP cache storage system searches the Hash Table by the LBA to determine the location of the data. Data requested may be in one of four different places: (i) the RAM buffer, (ii) the log disk(s), (iii) the storage device in the local SCSI-to-IP cache storage system, or (iv) a storage device in another SCSI-to-IP cache storage system on the network. If the data is found in the RAM buffer, the data are copied from the RAM buffer to the requesting buffer. The SCSI-to-IP cache storage system then signals the host that the request is complete. If the data is found in the log disk or the local storage device, the data are read from the log disk or storage device into the requesting buffer. Otherwise, the SCSI-to-IP cache storage system encapsulates the request including LBA, current GLN, and destination GLN into an IP packet and forwards it to the corresponding SCSI-to-IP cache storage system.

When a read request from another SCSI-to-IP cache storage system via the Ethernet interface is found after unpacking an incoming IP packet, the SCSI-to-IP cache storage system obtains the GLN and LBA from the packet. It then searches the Hash Table by the LBA and the source GLN to determine the location of the data. It locates and reads the data from that

location. It sends the data back to the source SCSI-to-IP cache storage system through the network.

The operation of moving data from a higher-level storage device to a lower level storage device is defined as *destage* operation. There are two levels of destage operations in the SCSI-to-IP cache storage systems: (i) destaging data from the RAM buffer to the log disk *(level 1 destage)* and (ii) destaging data from log disk to a storage device (*level 2 destage)*. A separate kernel thread, *LogDestage*, is implemented to perform the destaging tasks. The *LogDestage* thread is registered during system initialization and monitors the SCSI-to-IP cache storage system states. The thread remains asleep most of the time, and is activated when one of the following events occurs: (i) the number of slots in the RAM buffer exceeds a threshold value, (ii) the log disk is idle, (iii) the SCSI-to-IP cache storage system detects an idle period, or (iv) the SCSI-to-IP cache storage system RAM buffer and/or the log disk becomes full. *Level 1 Destage* has higher priority than *Level 2 Destage*. Once the *Level 1 destage* starts, it continues until a log of data in the RAM buffer is written to the log disk. *Level 2 destage* may be interrupted if a new request comes in or until the log disk becomes empty. If the destage process is interrupted, the destage thread is suspended until the SCSI-to-IP cache storage system STICS detects another idle period.

For *Level 1 Destage*, the data in the RAM buffer are written to the log disk sequentially in large size (e.g., 63KB). The log disk header and the corresponding in-memory slot entries are updated. All data are written to the log disk in "append" mode, which insures that every time the data are written to consecutive log disk blocks.

For *Level 2 destage*, a "last-write-first-destage" algorithm is employed according to the LRU List. At this point, a SCSI-to-IP cache storage system with the lowest STICS_LOAD is

selected to accept data. Each time 64KB data are read from the consecutive blocks of the log disk and written to the chosen SCSI-to-IP cache storage system storage disks. The LRU list and free list are updated subsequently.

Advantageously, the SCSI-to-IP cache storage system facilitates implementation of SAN over the Internet. The SCSI-to-IP cache storage system allows any server host to access a SAN on Internet through a standard SCSI interface. Using a non-volatile "cache storage", the SCSI-to-IP cache storage system smoothes out the storage data traffic between SCSI and IP, analogous to the way the cache memory smoothes out CPU-memory traffic.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

CLAIMS

1. A SCSI-to-IP cache storage system that interconnects a host computing device or a storage unit to a switched packet network, said cache storage system comprising:

a SCSI interface that facilitates system communication with the host computing device or the storage unit;

an Ethernet interface that allows the system to receive data from and send data to the Internet;

a processing unit that includes a processor and memory;

a log disk configured as a sequential access device that caches data along with said memory resident in said processing unit, wherein said log disk and said memory are configured as a two-level hierarchical cache; and

a disk storage device that receives data from and provides data to the two level hierarchical cache.

2. The SCSI-to-IP cache storage system of claim 1, wherein said memory comprises RAM.

3. The SCSI-to-IP cache storage system of claim 2, wherein said RAM comprises NVRAM.

4. The SCSI-to-IP cache storage system of claim 3, wherein said disk storage device comprises a redundant array of inexpensive disks.

5. A SCSI-to-IP cache storage system that interconnects a host computing device or a

storage unit to a switched packet network, said cache storage system comprising:

a SCSI interface that facilitates system communication with the host computing device or the storage unit;

an Ethernet interface that allows the system to receive data from and send data to the Internet;

a processing unit that includes a processor and RAM;

a log disk that caches data along with said RAM, wherein said log disk and said RAM are configured as a two-level hierarchical cache; and

a disk storage device that receives data from and provides data to the two level hierarchical cache.

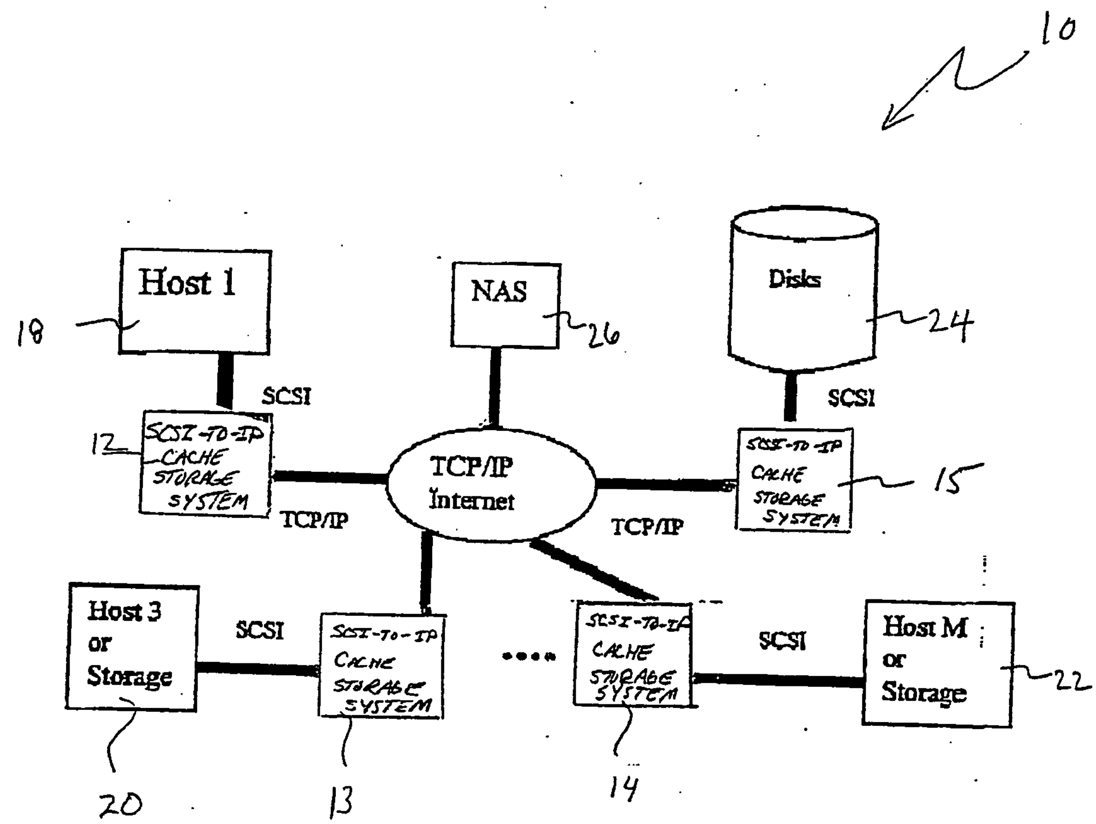
10
Host 1
18
NAS
26
Disks
24
SCSI
SCSI
SCSI-TO-IP
CACHE
STORAGE
SYSTEM
12
TCP/IP
Internet
TCP/IP
TCP/IP
SCSI-TO-IP
CACHE
STORAGE
SYSTEM
15
Host 3
or
Storage
SCSI
SCSI-TO-IP
CACHE
STORAGE
SYSTEM
SCSI-TO-IP
CACHE
STORAGE
SYSTEM
SCSI
Host M
or
Storage
22
20
13
14

FIG. 1

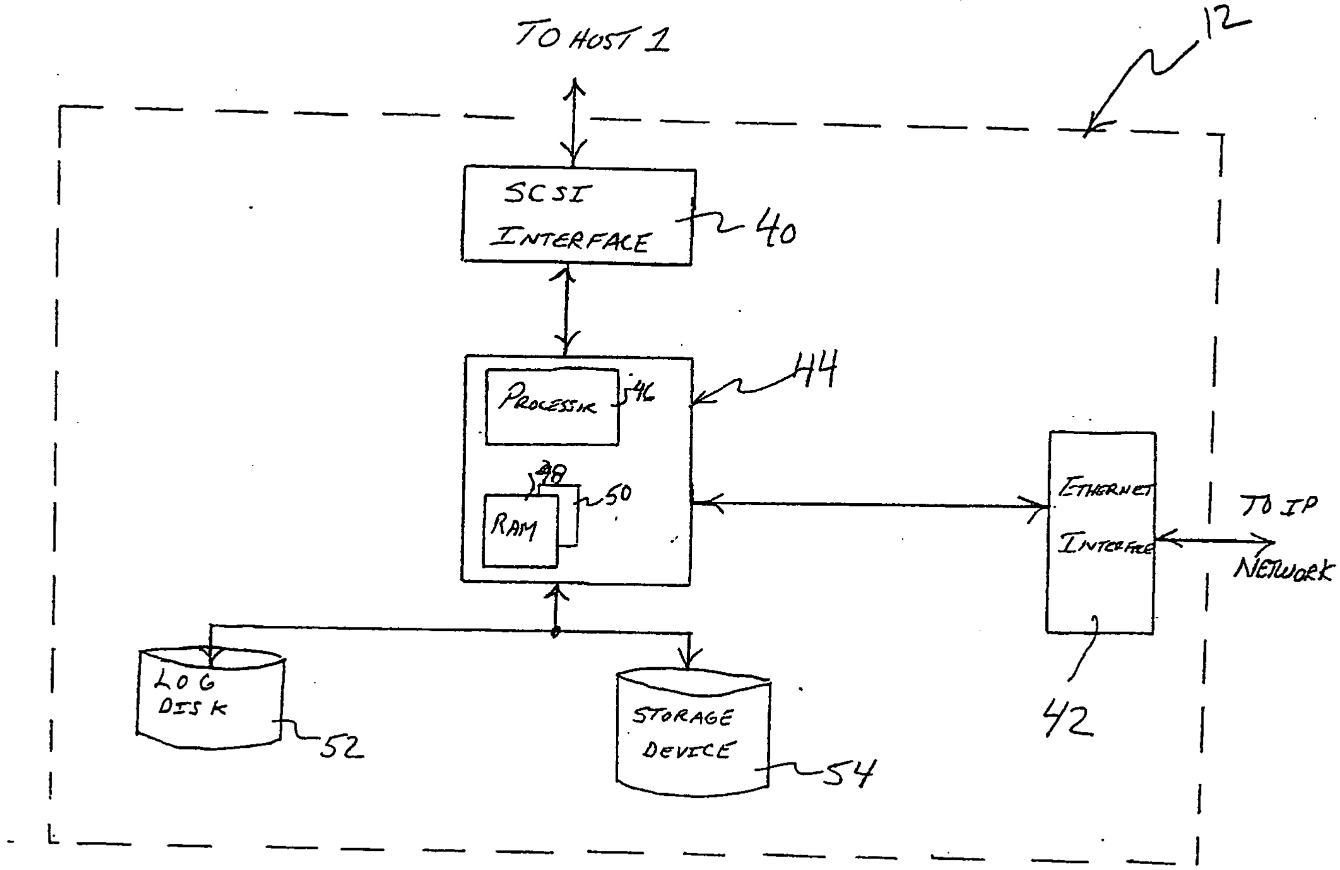
TO HOST 1
12
SCSI INTERFACE
40
44
PROCESSOR
46
48
50
RAM
ETHERNET INTERFACE
TO IP NETWORK
LOG DISK
52
STORAGE DEVICE
54
42

FIG. 2

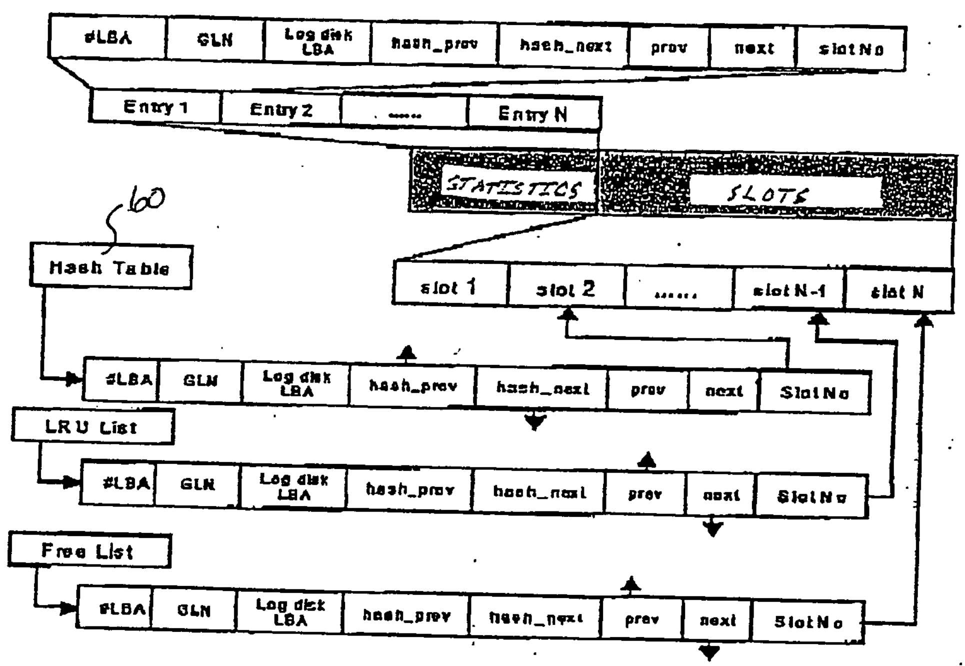
#LBA
GLN
Log disk LBA
hash_prev
hash_next
prev
next
slot No
Entry 1
Entry 2
......
Entry N
STATISTICS
SLOTS
60
Hash Table
slot 1
slot 2
......
slot N-1
slot N
LRU List
Free List
SlotNo

FIG. 3

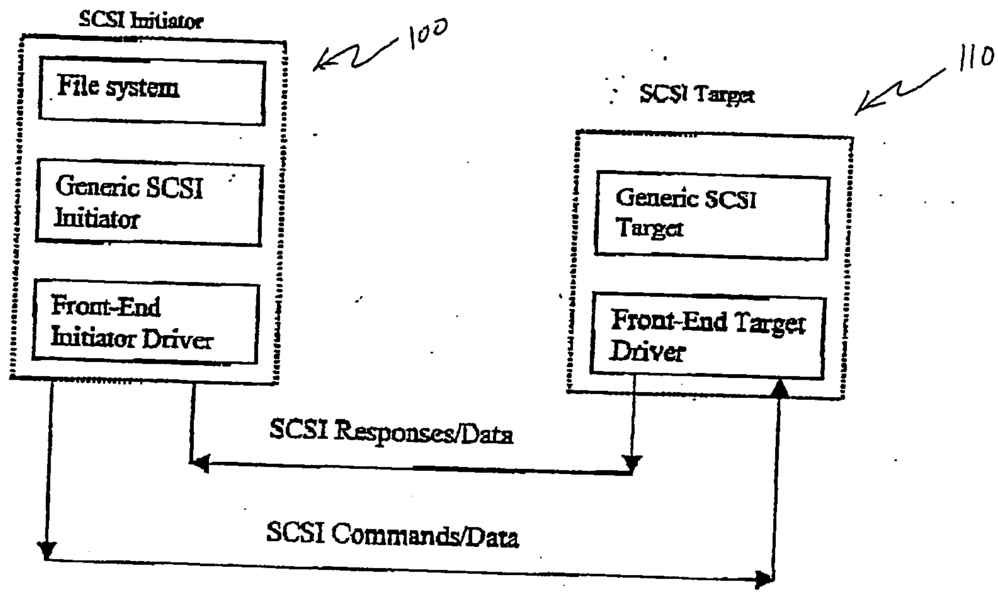
SCSI Initiator
100
File system
Generic SCSI Initiator
Front-End Initiator Driver
SCSI Target
110
Generic SCSI Target
Front-End Target Driver
SCSI Responses/Data
SCSI Commands/Data

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/26292

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H04L 12/56
US CL : 370/395.72; 709/213
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 370/395.72, 363, 368, 371, 374, 378, 381, 383, 395.7, 395.71, 428; 709/213, 214, 215, 216, 217, 218, 219, 312, 321, 325, 326

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST, NPL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PRESLAN, K. W. et al. A 64-Bit, Shared Disk File System for Linux. Mass Storage Systems, 15-18 March 1999, pages 22-41.	1-5
A	VORUGANTI, K. et al. An Analysis of Three Gigabit Networking Protocols for Storage Area Networks. Performance, Computing, and Communications, 4-6 April 2001, pages 259-265.	1-5
A	LEE, Y. K. et al. Metadata Management of the SANtopia File System. Parallel and Distributed Systems, 26-29 June 2001, pages 492-499.	1-5
A	KIM, C. S. et al. Volume Management in SAN Environment. Parallel and Distributed Systems, 26-29 June 2001, pages 500-505.	1-5
A	MOLERO, X. et al. On the Switch Architecture for Fibre Channel Storage Area Networks. Parallel and Distributed Systems, 26-29 June 2001, pages 484-491.	1-5
A	NAMGOONG, J. C. et al. Design and Implementation of a Fibre Channel Network Driver for SAN-attached RAID controllers. Parallel and Distributed Systems, 26-29 June 2001, pages 477-483.	1-5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 October 2002 (25.10.2002)	06 DEC 2002
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Hassan Kizou Eugenia Logan Telephone No. 703-305-4750